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CORNEAL CYLINDERS IN REFRACTIVE KERATOPLASTY *

BY

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ABSTRACT

The evolution of instrumentation in refractive keratoplasty has made possible the separation of cylindrical tissue sections from the body of the cornea. The possibilities and limits of cylindrical sectioning are discussed. The technique allows for the correction of spherical, cylindrical and combined errors by double sectioning, where necessary and discarding the second section. This represents the virtual elimination of the spherical equivalent of the refractive error and the re-orientation of the astigmia by rotating the first section before its affixation to the corneal bed. The optical rationale is fully discussed.

INTRODUCTION

Techniques of surgical intervention in the presence of ametropia for the purpose of correction has a prominent place in the literature. Dr. José I. Barraquer of the Instituto Barraquer de America has shown the feasibility of altering the refractive power of the eye by refractive keratoplasty. His technique, which has

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been extensively reported in the literature [1], consists of the removal of a corneal section with an instrument, carving the section and replacing it on the eye.

This method is the latest of many attempts in the surgical correction of ametropia. A cutting instrument is utilized to separate a section from the body of the cornea. This instrument, called the microkeratome, is used in conjunction with a suction ring and accessory devices. The microkeratome may be defined as a mechanized surgical instrument for the dissection of partial thickness grafts from the cornea. The latest prototype of the microkeratome is the "Elkat Autokeratome" [2], which consists of three functional components:

1. the head,
2. the guiding fixation ring, and
3. the motor.

It is functionally and structurally akin to a carpenter's plane. A thin stainless steel blade protrudes through a slot in the steel head and moves in a reciprocating manner. This motion is imparted by an eccentric pin in the shaft of the blow-out proof motor.

A pneumatic ring is affixed to the eye. This ring is disciform and is perforated by a central hole. The bottom of the ring contains a channel through which suction is introduced so that when the ring is applied to the eye, it is held firmly in place by the suction. The cornea protrudes through the hole in the pneumatic ring. When the ring is affixed and suction applied, the autokeratome is introduced through a guiding track at the top of the ring. The ring must be situated so that the track will be oriented with the horizontal meridian of the patient's eye. This requirement is imposed by the orbital structure so that the autokeratome will not be impeded in its cutting traverse. The front of the autokeratome contains an applanation device - a flat transparent plate, easily removable and interchangeable. A series of aspheric plates has been fabricated. Each plate is plano-toric on the applanation face so that its function may be defined as semiapplanation, since it applanates only the horizontal meridian of the eye. As the cornea is semiapplanated, the tissue is molded by the plate to conform to its plano-toric face, either concave or convex. The reciprocating blade of the autokeratome carves a flat surface, so that the separated section will be meniscus-toric in form with parallel surfaces in the horizontal meridian. This section may be theoretically reconstituted for simple visualization, so that, after its removal, it re-assumes its in-vivo form. In reconstitution, it resembles a plano-cylindrical contact lens, the horizontal cross section of which reveals parallelism of the surfaces, and the vertical cross section that of either concavity or convexity.

It has been shown that a meniscus lens with parallel surfaces has negative dioptric power [3]. Therefore, since the relationship is always parallel in a horizontal cross section of the surfaces, there is always minus dioptric power in this meridian. The degree of this power will depend upon the thickness of the original section and the horizontal radius of curvature as determined by a K reading prior to surgery.

CYLINDRICAL POWER

The cylindrical power of the corneal section is the difference between the powers of the two principal meridians. Since the power in the horizontal meridian is always minus, it may be stated that if the vertical meridian contains a greater amount of minus power than the horizontal meridian, the corneal section is to be defined as a concave cylinder. If, however, the vertical meridian contains less minus power than that of the horizontal, the section may be defined as a convex cylinder. By the same token, if the vertical meridian contains either zero or plus power, the corneal section would also be considered plus cylindrical in nature.

SURGICAL LIMITS

The optical parameters of the cylindrical sections are limited by the following considerations:

1. the minimum thickness, of either edge or center of a corneal section, within the limits of surgical considerations as determined by either Barraquer or Katzin is 0.12 mm. [4].

2. the minimum remaining thickness in the corneal bed has been determined to be 0.15 mm.

3. the limits of corneal curvature may be taken to be the extremes of the Bausch & Lomb Keratometer: 6.49 to 9.375 mm.

The magnitude of the values concerned in this investigation may be illustrated by example. A concave cylindrical corneal section may be assigned its minimum center thickness of 0.12 mm. If one uses average minimum values for whole corneal thickness, it may be assumed that there is at least 0.60 mm. thickness at a point approximately 3 mm. distance from the pole of the cornea. This would appear a safe assumption in view of the fact that the central corneal thickness is held to be about 0.56 mm., and that of the periphery about 1.0 mm. [5]. Assuming a remaining bed thickness of 0.15 mm., the maximum thickness at the edge of the corneal disc in the vertical meridian may be as high as 0.45 mm. (0.60 -

0.15), assuming a disc diameter of 6 mm. Therefore, the following maximum dimensional situation may be posed: A corneal disc has the following dimensions:

1. anterior radius of curvature : 7.7 mm.,
2. central thickness : 0.12 mm.,
3. section diameter : 6.0 mm.,
4. edge thickness in the horizontal meridian: 0.12 mm., and
5. edge thickness in the vertical meridian: 0.46 mm.

The cylindrical power of this disc may now be determined. The dioptric power in the horizontal meridian is:

posterior vertex power: —0.564 diopters,
anterior vertex power: —0.559 diopters, and

in the vertical meridian:

posterior vertex power: —28.167 diopters,
anterior vertex power: —27.860 diopters.

Considering the paraxial anterior vertex power, a cylindrical section of these dimensions would have a cylindrical power of —27.300 diopters. It may be seens, therefore, that the magnitude of a cylindrical corneal section may be quite high, within the range of limits as stated.

Variation of the vertical edge thickness in the preceding example changes the value of the concave cylinder. Therefore, if the surgeon restricted himself to the minimum thickness in the horizontal meridian, the vertex power in this meridian would remain in the magnitude of 0.50 diopters, and the dioptric power in the vertical meridian would then determine the value of the cylindrical section. This value is calculated by changing the sign of the horizontal meridional power and adding algebraically to the vertical meridional power.

HORIZONTAL MERIDIONAL POWER

In the consideration of both convex and concave cylindrical corneal sections, the two variables are the thickness and the anterior radius of curvature. There is a considerable variation in paraxial vertex power with different radii of curvature. With an assumed constant horizontal meridional thickness of 0.12 m. m. (the minimum), a series of paraxial calculations may be made to assess the variation of power with radius change. Table I shows this variation from —0.795 diopters of posterior paraxial vertex power with a corneal radius of 6.50 mm. to —0.377 diopters with a corneal radius of 9.40 mm. Fig. 1 reflects the values in table I.

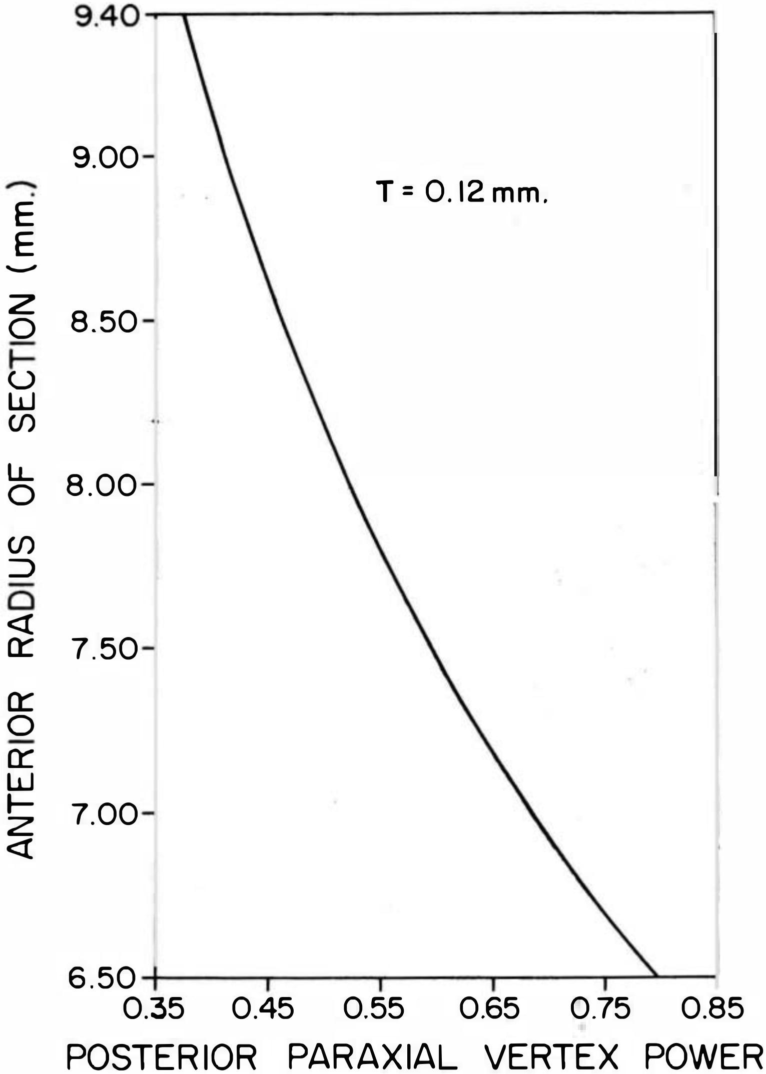

Figure 1. The relationship between the anterior radius of curvature and vertex power, in a series of corneal sections with parallel surfaces and a thickness of 0.12 mm.

The thickness of the horizontal meridian of concave cylindrical sections approaching the minimum and the horizontal meridional thickness of convex cylindrical sections approaches the maximum. An examination of the effects of thickness on paraxial vertex power may be undertaken. Table II has been calculated with an assumed horizontal radius value of 7.70 mm. (that of the Gullstrand schematic eye [6]). It may be seen that the posterior paraxial vertex power varies from —0.564 diopters with a thickness of 0.12 mm. to —2.185 diopters with a thickness of 0.44 mm. Fig. 2 reflects the values in table II.

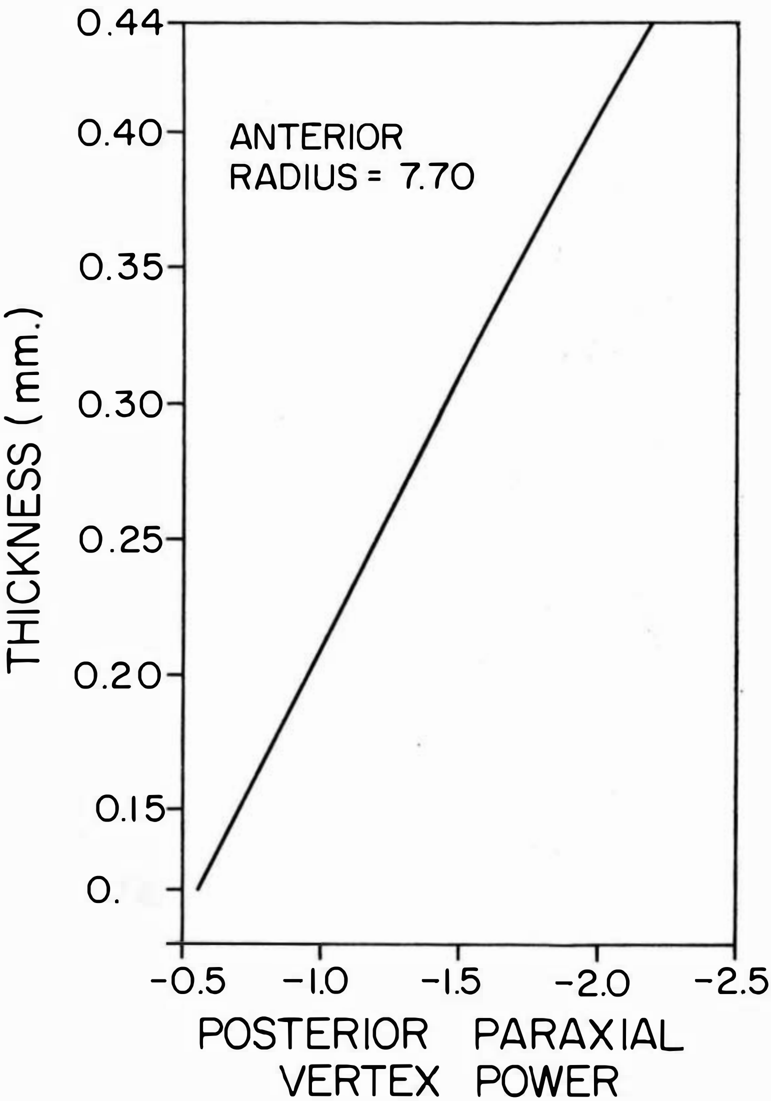

Figure 2. The relationship between thickness and vertex power in a series of corneal sections with parallel surfaces and an anterior radius of 7.70 mm.

METHODS OF CORRECTION

Single toric sectioning is a technique which consists of the separation of a toric section, its reorientation within the bed and in affixation. Double toric sectioning (fig. 3) consists of the removal of first one toric section, then the removal of a

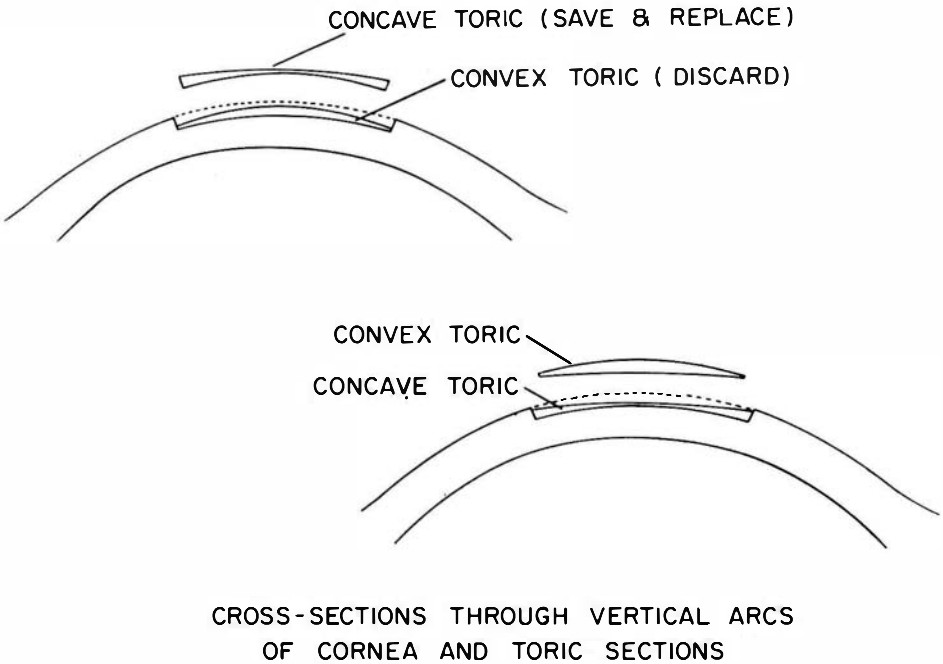

Figure 3. DOUBLE TORIC SECTIONING: top: correction of a + spherical equivalent error; bottom: correction of a — spherical equivalent error.

second toric section, the discarding of the second section and the fixation of the first section to the bed with or without reorientation. Fig. 4 demonstrates the re-fixation of a toric section to the corneal bed.

Single toric sectioning is utilized in zero-equivalent, mixed astigmia. The other categories of refractive error require double toric sectioning for their full correction.

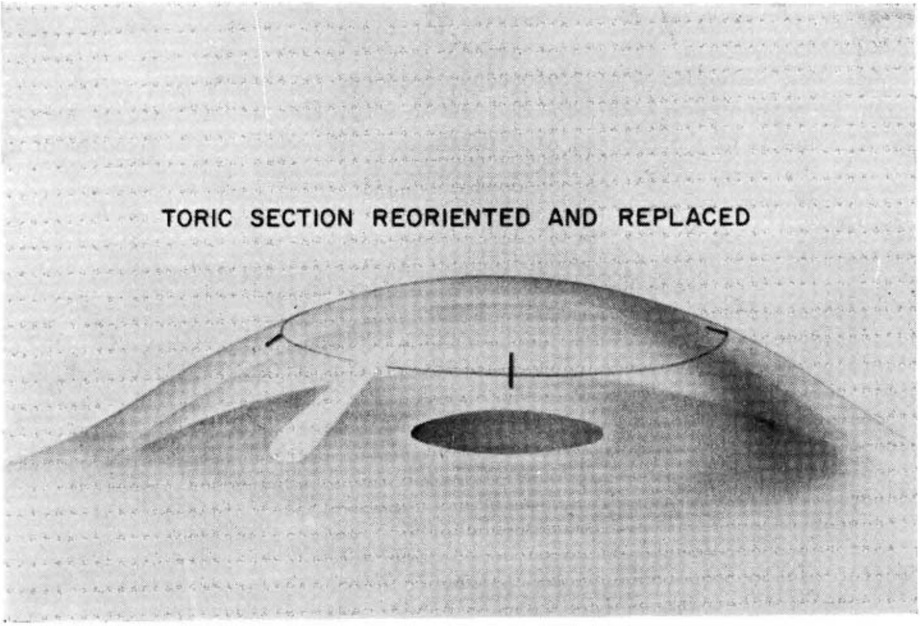

Figure 4. Refixation of a toric section to the bed of the cornea.

OBLIQUE ASTIGMATIC ERRORS

The correction of oblique astigmatic errors requires a special understanding of the resolution of obliquely crossed cylinders. The following formulas may be applied for the resolution of obliquely crossed cylinders [7]:

$$P = \sqrt{F_1^2 + F_2^2 + 2F_1F_2\cos 2\gamma} \qquad (1)$$

$$Q = \frac{F_1 + F_2 - P}{2\gamma} \quad \text{and} \qquad (2)$$

$$\tan 2\alpha = \frac{F_2 \sin 2\gamma}{F_1 + F_2 \cos 2\gamma} \qquad (3)$$

where the following designations prevail:

P denotes the cylindrical component of the resolved sphero-cylindrical equivalent,

Q denotes the spherical component of the resolved sphero-cylindrical equivalent,

α denotes the angular difference between the axis of the first oblique cylinder and the axis of the equivalent sphero-cylinder,

F_1 Denotes the power of the first oblique cylinder,

F_2 denotes the power of the second oblique cylinder, and

γ denotes the difference between the axies of the two obliquely crossed cylinders.

The application of these formulas require that the cylinder with the smallest slope angle with relation to the horizontal meridian be assigned the value of F_1.

An example is cited from Southall [8]:

"Given a combination of obliquely crossed cylinders as follows:

+4.00 cyl. ax. 20° / —2.75 cyl. ax. 65°;

"Let it be required to find the equivalent spherocylindrical power and also the equivalent cross cylinder.

We must put $F_1 = +4.00$, because F_1 denotes the power of the cylinder whose axis-slope is the smaller of the two. Then, $F_2 = -2.75$ an $\gamma = (65^\circ - 20^\circ) = 45^\circ$. Substituting these values we find:

$P = +4.85$, $Q = -1.8$ and $\gamma = -17°16'$.

"Accordingly, the given combination is equivalent to the following:

—1.8 sphere / +4.85 cylinder axis 2°44'.

SIMPLE OBLIQUE ASTIGMIA

The problem of the correction of simple oblique astigmia may now be examined. If a single cylindrical section were excised from the cornea of an eye with oblique astigmia, the new error of this eye would be the resolution of the original astigmia with minus the power of the cylindrical section removed (the section removal error). If this new error were equal to the power of the cylindrical section itself, the section would be re-oriented and sutured to its bed, effecting a correction of the astigmatic error.

Example Nº 1: simple oblique myopic astigmia:

technique of correction : single sectioning

spectacle correction : —1.00 cx 15

refractive error : +1.00 cx 15

power of section : —0.50 / +0.58 cx 180

section removal error : +0.50 / —0.58 cx 180

new refractive state : +1.00 cx 15 / +0.50 / —0.58 cx 180 = +1.00 / —0.58 cx 30 section rotated to axis 30 and replaced,

power of section : —0.50 / +0.58 cx 30

final refractive state : +1.00 / —0.58 cx 30 / —0.50 / +0.58 cx 30 = + 0.50 sphere.

It may be observed from this example that although the cylindrical component of the error was corrected in its entirety, there was some residual sphere as a result of the resolution of obliquely crossed cylinders. If, in this case, the original error was —0.50 sphere / +1.00 cylinder axis 15, single cylindrical sectioning would have sufficed as a theoretically adequate correcting technique.

If the original error were —2.00 cylinder axis 15 (double the astigmia in example Nº 1), the power of the cylindrical section would have to have been 1.16 (double 0.58) axis 180, in order to achieve theoretically cylindrical correction, and the residual sphere would have been +1.00. Therefore, it may be seen that a table can be derived for the correction of 1.00 diopter of oblique astigmia so that the resulting power of the cylindrical section for each axis meridian could be considered as the cylindrical factor. It would then merely be necessary to multiply the degree of oblique astigmia in a given case by this cylindrical factor to determine the value of the cylindrical section for correction in a given case (table III).

The information contained in table III may be charted on a graph (fig. 5). It may be noted that at 5° and 95° of obliquity, the cylindrical section power is almost equal to half of the value of the original astigmia. As the degree of obliquity increases, the value of the cylindrical section increases in a curve so that at 45°, the power of the correction cylinder is infinite. Above 45° the value of the cylindrical section begins to drop so that the values correspond exactly with those below 45°. It might also be noted that the value of the residual sphere as a result of single sectioning remains 0.50 diopters.

If an extreme case were chosen, an error of +1.00 diopter of astigmia axis 40°
re-oriented and sutured back, would, in addition to correcting the astigmia, result in a residual spherical error of 0.50 diopters. Therefore, by the same token as previously, if the original error were +0.50
axis 40°, this single sectioning technique would afford complete correction.

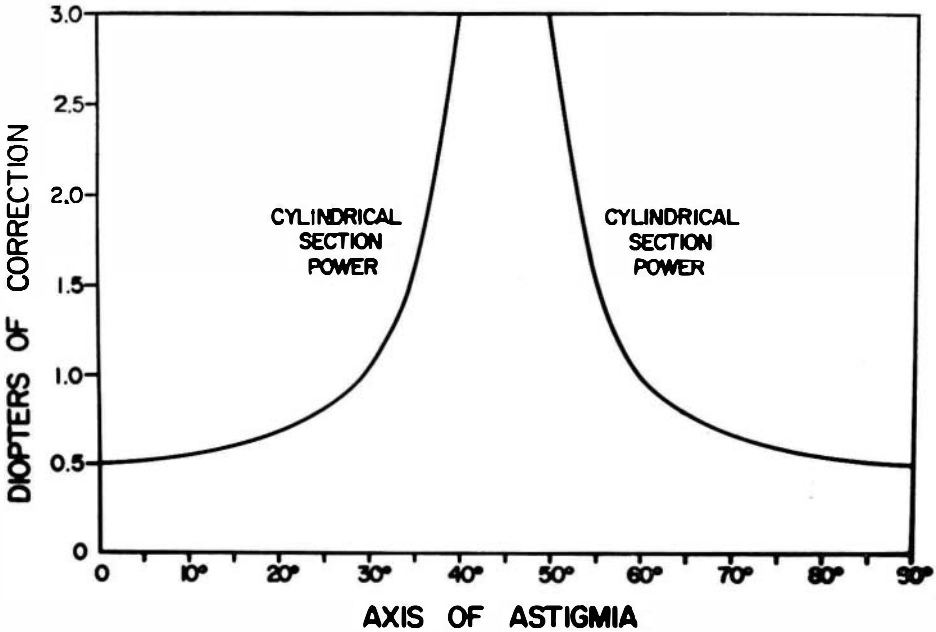

Figure 5. Power of cylindrical section necessary to correct 1.00 diopter of oblique astigmia at various axes.

It may be concluded, therefore, that mixed, zero equivalent astigmia at any axis lends itself to correction by single toric sectioning. For practical considerations, it may also be seen that those special cases where the residual sphere is sufficiently small, single toric sectioning may also be applied as a correcting technique. In those cases, however, where the residual sphere is considered sufficient to materially affact the outcome, it is recommended that double sectioning be applied.

SOME GENERAL RULES

There are two phases in the correction of refractive errors by the application of cylindrical sectioning:

1. The actual excision of a corneal lens whose spherical equivalent is equal to the spherical equivalent of the error.
2. The re-orientation of the astigmia.

Therefore, the first section represents the corneal lens containing the astigmia to be re-oriented and the second represents the error which is discarded.

ZERO-EQUIVALENT ASTIGMIA

Since the spherical equivalent is zero-equivalent astigmia is zero, nothing need be discarded in its correction. The entire correction is achieved by the re-orientation of the astigmia.

Non-Oblique

1. The error is recorded with the cylinder axis at 180º, transposing, if necessary.

2. The cylindrical component of the section to be removed has the same sign and is one-half the value of the cylindrical component of the refractive error.

3. The section is rotated 90º and affixed to the bed.

Example Nº 2: zero-equivalent, non-oblique, mixed, with the rule astigmia (fig. 6):

technique of correction : single sectioning

spectacle correction : +2.00 / —4.00 cx 180

refractive error : —2.00 / +4.00 cx 180

spherical equivalent : zero

power of section : —0.50 / +2.00 cx 180

section removal error : +0.50 / —2.00 cx 180

new refractive state :

—2.00 / +4.00 cx 180 / +0.50 / —2.00 cx 180 = —1.50 / +2.00 cx 180

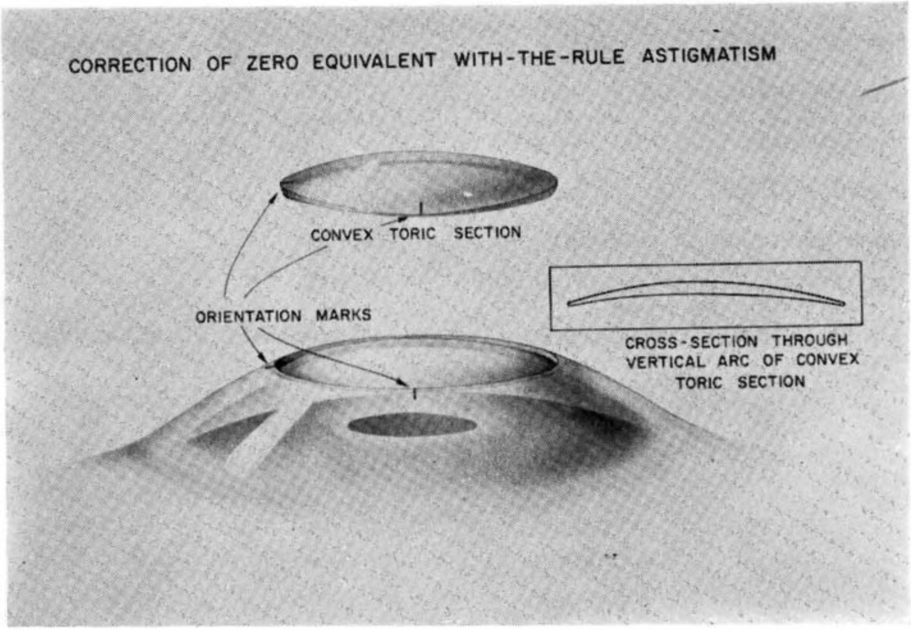

Figure 6. Correction of zero-equivalent, non-oblique, mixed, with-the-rule astigmia.

transposed to : +0.50 / —2.00 cx 90

section re-oriented 90° and replaced

power of section : —0.50 / +2.00 cx 90

final refractive state :

+0.50 / —2.00 cx 90 / —0.50 / +2.00 cx 90 = emmetropia

Example Nº 3: zero-equivalent, non-oblique, mixed, against the-rule astigmia (fig. 7):

technique of correction : single sectioning

spectacle correction : +2.00 / —4.00 cx 90

refractive error : —2.00 / +4.00 cx 90

transposed to : +2.00 / —4.00 cx 180

spherical equivalent : zero

power of section : —0.50 / —2.00 cx 180

section removal error : +0.50 / +2.00 cx 180

new refractive state :

+2.00 / —4.00 cx 180 / +0.50 / +2.00 cx 180 = +2.50 / —2.00 cx 180

transposed to : +0.50 / +2.00 cx 90

section re-oriented 90° and replaced

power of section : —0.50 / —2.00 cx 90

final refractive state :

+0.50 / +2.00 cx 90 / —0.50 / —2.00 cx 90 = emmetropia

Zero- Equivalent, Oblique, Mixed Astigmia

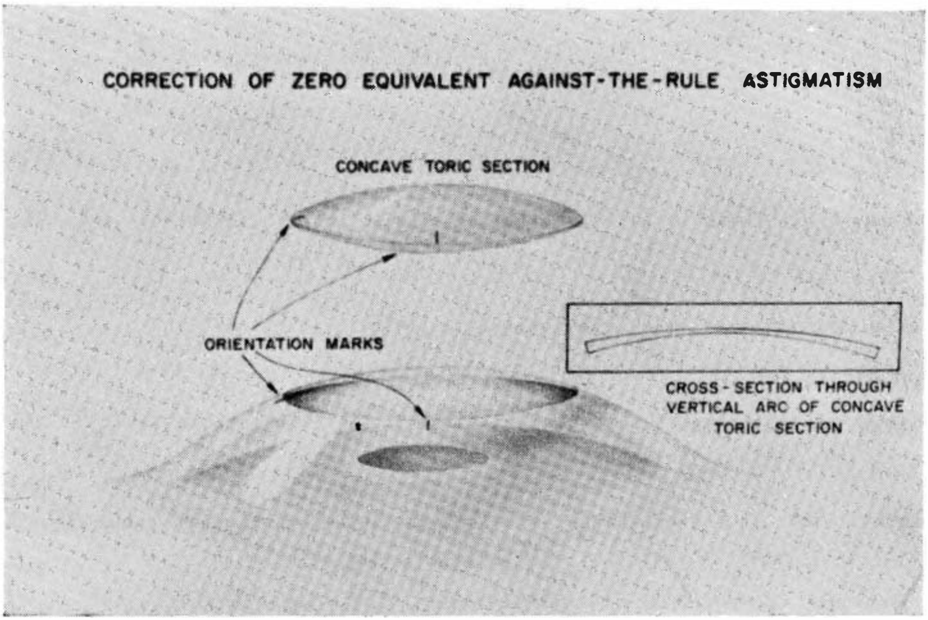

Figure 7. Correction of zero-equivalent, non-oblique, mixed, against-the-rule astigmia.

1. The error is recorded to that the axis falls between 0° and 90°, transposing, if necessary.

2. Fig. 3 is consulted to determine the cylindrical factor, using the oblique axis of the astigmatic component of the error as a point of reference.

3. The power of the cylindrical section to be removed is determined by multiplication of the cylindrical factor from step 2 by the cylindrical component of the original refractive error.

a. If the oblique axis is between 0° and 45°, the sign of the cylindrical section is the same as that of the cylindrical component of the error.

b. If the oblique axis is between 45° and 90°, the sign of the cylindrical section is opposite that of the cylindrical component of the error.

4. The axis of re-orientation is determined by doubling the axis of the original error and reversing 90°.

Example Nº 4: zero-equivalent, oblique, mixed astigmia:

technique of correction : single sectioning

spectacle correction : +2.00 / —4.00 cx 35

refractive error : —2.00 / +4.00 cx 35

spherical equivalent : zero

power of section : —0.50 / +5.86 cx 180

section removal error : +0.50 / —5.86 cx 180

new refractive state :

—2.00 / +4.00 cx 35 / +0.50 / —5.86 cx 180 = +0.50 / —5.86 cx 160
section re-oriented to axis 160 and replaced power of section : —0.50 / +5.86 cx 160

final refractive state :

+0.50 / —5.86 cx 160 / —0.50 / +5.86 cx 160 = emmetropia

SPHERICAL ERRORS

The following method may be applied for the correction of spherical errors:

1. The spherical equivalent of the second section is equal to the ametropia to be corrected.

a. The spherical component of the second section may be assigned an arbitrary value of —0.50.

b. The cylindrical component of the second section is derived by adding +0.50 algebraically to the ametropia and doubling the result.

2. The power of the cylindrical component of the first section is one-half that of the cylindrical component of the second section.

3. The second section is discarded.

4. The first section is rotated 90° and affixed to the bed of the cornea.

Example Nº 5 (fig. 8): simple myopia

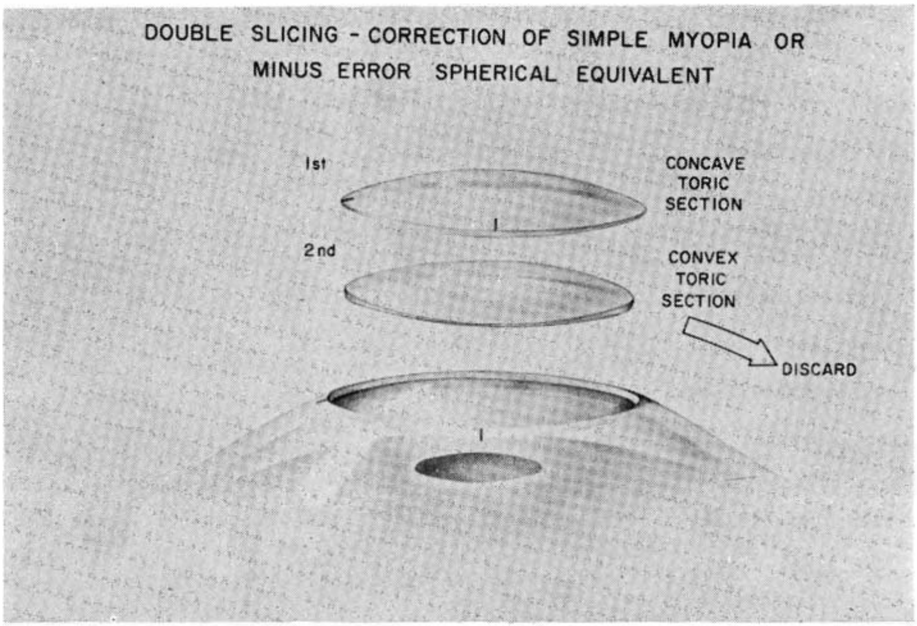

Figure 8. Correction of simple myopia.

technique of correction : double sectioning

spectacle correction : —2.00 sphere

power of lst section : —0.50 / —2.50 cx 180

section removal error : +0.50 / +2.50 cx 180

new refractive state :

+2.00 / +0.50 / +2.50 cx 180

= +2.50 / +2.50 cx 180

power of 2nd section : —0.50 / +0.50 / +5.00 cx 180

section removal error : +0.50 / —5.00 cx 180

new refractive state :

+2.50 / +2.50 cx 180 / +0.50 / —5.00 cx 180

= +3.00 / —2.50 cx 180

transposed to : +0.50 / +2.50 cx 90

2nd section discarded, lst section replaced, reoriented to axis 90

power of lst section : —0.50 / —2.50 cx 90

final refractive state :

+0.50 / +2.50 cx 90 / —0.50 / —2.50 cx 90

= emmetropia

Example Nº 6: (fig. 9) simple hyperopia

technique of correction : double sectioning

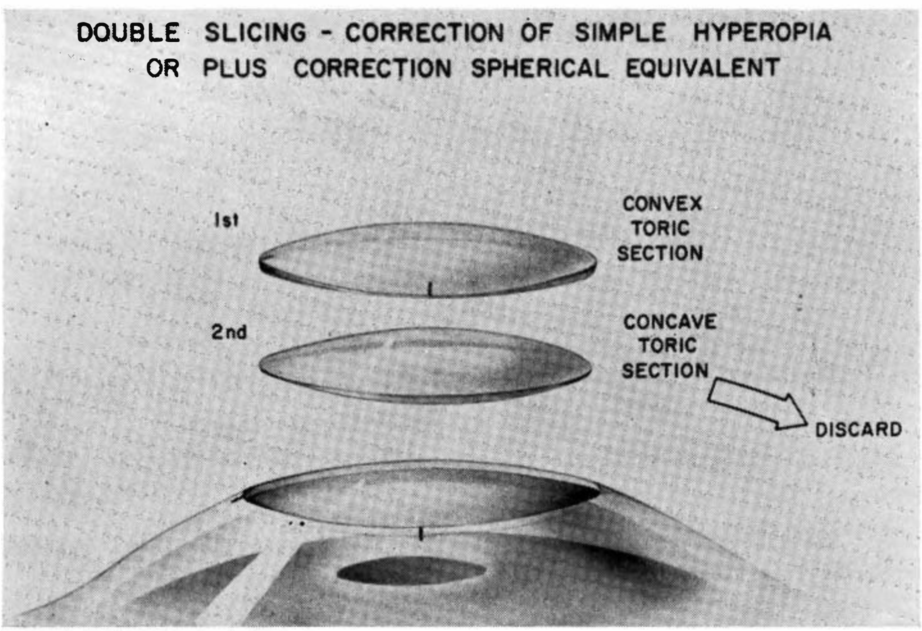

Figure 9. Correction of simple hyperopia.

spectacle correction : +2.00 sphere

refractive error : —2.00

power of 1st section : —0.50 / +1.50 cx 180

section removal error : +0.50 / —1.50 cx 180

new refractive state :

—2.00 +0.50 / —1.50 cx 180

= —1.50 / cx 180

power of 2nd section : —0.50 / —3.00 cx 180

section removal error : +0.50 / +3.00 cx 180

new refractive state :

—1.50 / —1.50 cx 180 / +0.50 / +3.00 cx 180

= —1.00 / +1.50 cx 180

transposed to : +0.50 / — 1.50 cx 90

2nd section discarded, 1st section replaced,

re-oriented to axis 90

power of 1st section : —0.50 / +1.50 cx 90

final refractive state :

+0.50 / —1.50 cx 90 / —0.50 / +1.50 cx 90

= emmetropia

NON-OBLIQUE, NON-ZERO-EQUIVALENT, REFRACTIVE ERRORS

1. The error is recorded with the cylinder axis at 180°, transposing, if necessary.

2. The spherical equivalent of the second section is equal to the ametropia (spherical equivalent) to be corrected.

a. The spherical component of the second section may be assigned an arbitrary value of —0.50.

b. The cylindrical component of the second section is derived by adding +0.50 algebraically to the spherical equivalent of the ametropia and doubling the result.

3. The power of the first section may be derived in the following manner:

a. The spherical component of the first section may be assigned an arbitrary value of —0.50.

b. The cylindrical component of the first section is that value half-way between the cylindrical components of the original refractive error and the second section, the sign opposite to that of the second section.

4. The second section is discarded.

5. The first section is rotated 90° and affixed to the bed of the cornea.

Example Nº 7: simple, with-the-rule, axis 90 astigmia

technique of correction:		double sectioning
spectacle correction	:	+2.00 cx 90
refractive error	:	—2.00 cx 90
transposed to	:	—2.00 / +2.00 cx 180
spherical equivalent	:	—1.00
power of 1st section	:	—0.50 / +1.50 cx 180
section removal error	:	—0.50 / +1.50 cx 180
new refractive state	:	

—2.00 / +2.00 cx 180 / +0.50 / —1.50 cx 180

= —1.50 / +0.50 cx 180

power of 2nd section	:	+0.50 / —1.00 cx 180
section removal error	:	+0.50 / +1.00 cx 180
new refractive state	:	

—1.50 / +0.50 cx 180 / +0.50 / +1.00 cx 180

= —1.00 / +1.50 cx 180

transposed to : +0.50 / —1.50 cx 90

2nd section discarded, 1st section replaced, re-oriented to axis 90

power of 1st section : —0.50 / + 1.50 cx 90

final retractive state:

+0.50 / —1.50 cx 90 / —0.50 / +1.50 cx 90

= emmetropia

Example Nº 8: compound, with-the-rule, myopic astigmia:

technique of correction : double sectioning

spectacle correction : —1.00 / —2.00 cx 90

refractive error : +1.00 / +2.00 cx 90

transposed to : +3.00 / —2.00 cx 180

spherical equivalent : +2.00

power of 1st section : —0.50 / —3.50 cx 180

section removal error : +0.50 / +3.50 cx 180

new refractive state :

+3.00 / —2.00 cx 180 / +0.50 / +3.50 cx 180

= +3.50 / +1.50 cx 180

power of 2nd section : —0.50 / +5.00 cx 180

section removal error : +0.50 / —5.00 cx 180

new refractive state:

+3.50 /+1.50 cx 180 / +0.50 / —5.00 cx 180

=+4.00 / —3.50 cx 180

transposed to : +0.50 / +3.50 cx 90

2nd section discarded, 1st section replaced, re-oriented to axis 90

power of 1st section : —0.50 / —3.50 cx 180

final refractive state: :

+0.50 / +3.50 cx 90 / —0.50 / —3.50 cx 90

= emmetropia

NON-ZERO-EQUIVALENT, OBLIQUE REFRACTIVE ERRORS

1. The error is recorded so that the axis falls between 0^o and 90^o, transposing, if neccessary.

2. The spherical equivalent of the second section is equal to the spherical equivalent of the ametropia.

a. The spherical component of the second section may be assinged an arbitrary value of —0.50.

b. The cylindrical component of the second section is derived by adding +0.50 algebraically to the spherical equivalent of the ametropia and doubling the result.

3. The negative power of the second section (the section removal error) as derived in step 2, is resolved with the original refractive error.

4. The cylindrical factor is determined from the graph (fig. 3) using the axis of resolution determined in step 3 as the reference.

5. The cylindrical factor from step 4 is multiplied by the cylindrical component of the resolution from step 3. This value is the power of the cylindrical component of the first section.

a. If the oblique axis of the original error is between 0^o and 45^o, the sign of the first section is opposite that of the cylindrical component of the original error.

b. If the oblique axis of the original error is between 45^o and 90^o, the sign of the first section is the same as that of the cylindrical component of the original error.

c. The spherical component of the first section may be assigned an arbitrary value of —0.50.

6. The removal error of the first section (the negative value from step 5) is resolved with the original refractive error.

7. The removal error of the second section (the negative value from step 2) is resolved with the resolution from step 6.

8. The axis of this resolution (step 7) represents the axis of re-orientation of the first section.

9. The first section (from step 5) is then separated and retained, the second section (from step 2) separated and discarded, the first section re-oriented to the axis (from step 8) and affixed to the corneal bed.

Example Nº 9:: compound, myopic, oblique, with-the-rule astigmia:

technique of correction: double sectioning

spectacle correction	:	—2.00 / —1.00 cx 25
refractive error	:	+2.00 / +1.00 cx 25
spherical equivalent	:	+2.50
power of 2nd section	:	—0.50 / +6.00 cx 180
section removal error	:	—0.50 / +6.00 cx 180

resolution of section removal error and original error

+2.00 / +1.00 cx 25 / +0.50 / —6.00 cx 180

= +2.707 / —5.414 cx 86

cylindrical factor : 0.5064

cylindrical component of last section

cylindrical component of lst section : (—5.414) (+0.5064) = —2.742

power of lst section : —0.50 / —2.742 cx 180

section removal error : +0.50 / +2.742 cx 180

resolution of lst section removal error and original error :

+0.50 / +2.742 cx 180 / +2.00 / +1.00 cx 25

= +2.636 / +3.468 cx 6

resolution of 2nd section removal error and new refractive state :

+0.50 / —6.00 cx 180 / +2.636 / +3.468 cx 6

= +0.49 / +2.752 cx 172

2nd sectional discarded, lst section replaced, re-oriented to axis 172

final refractive state : +0.49 / +2.752 cx 172 / —0.50 / —2.742 cx 172

= —0.01 / +0.01 cx 172

= emmetropia*

* (If the decimal limit of the calculation were increased, the new refractive state would more closely approach zero).

QUALIFICATIONS

If the cylindrical section is reconstituted to its pre-separation dimensions, it is apparent that the posterior principal meridional radii of the section will not match the anterior principal meridional radii of the bed. This is true in both single and double sectioning. The section must bend from its pre-separation dimensions so that its posterior face conforms to the corneal bed. This bending changes the dioptric power of the section [9]. Bending effects have been excluded from this discussion, so that the examples cited herein do not reflect this order of change. Bending, however, must be taken into consideration when computing a given case.

These calculations are also subject to biological variation. Factors involving the accuracy of this form of surgical intervention are in the process of assessment by members of the Katzin team* in the biological experimentation phase of their studies in refractive keratoplasty. The plus or minus error limits include:

1. sectioning accuracy,
2. re-oreintation accuracy,
3. suture balance (so as not to induce corneal distortion) and
4. healing distortion.

CONCLUSION

This calculation rationale is a starting point in the biological experimentation phase of cylindrical sectioning techniques in refractive keratoplasty. Any trauma associated with freezing, lathe-carving, the excessive handling of the corneal tissue section, and the additional time necessary for the perfomance of these techniques, is eliminated by the application of cylindrical sectioning. The upper limits of correction possible with frozen-lathe-carving are not attainable with double cylindrical sectioning. This is a consequence of the necessary minimum edge or center

* A team of researchers under the direction of Dr. Herbert M. Katzin working on refractive keratoplasty at The Eye-Bank for Sight Restoration, Inc., under a grant from the John A. Hartford Foundation, Inc.

thickness in the second section. It is the feeling of some of those associated with this work that if any considerations of cylindrical sectioning will minimize interface opacification, this procedure may be preferable in those cases within the optical limits of this schema.

TABLE I

r_a	r_p	D_p	D_a
6.50	6.38	—0.795	—0.787
6.60	6.48	—0.770	—0.763
6.70	6.58	—0.748	—0.741
6.80	6.68	—0.725	—0.718
6.90	6.78	—0.704	—0.698
7.00	6.88	—0.684	—0.678
7.10	6.98	—0.665	—0.659
7.20	7.08	—0.646	—0.640
7.30	7.18	—0.628	—0.623
7.40	7.28	—0.611	—0.606
7.50	7.38	—0.595	—0.590
7.60	7.48	—0.579	—0.574
7.70	7.58	—0.564	—0.559
7.80	7.68	—0.550	—0.545
7.90	7.78	—0.536	—0.531
8.00	7.88	—0.522	—0.518
8.10	7.98	—0.509	—0.505
8.20	8.08	—0.497	—0.493
8.30	8.18	—0.485	—0.481
8.40	8.28	—0.473	—0.470
8.50	8.38	—0.462	—0.459
8.60	8.48	—0.451	—0.448
8.70	8.58	—0.441	—0.438
8.80	8.68	—0.431	—0.428
8.90	8.78	—0.421	—0.418
9.00	8.88	—0.412	—0.409
9.10	8.98	—0.403	—0.400
9.20	9.08	—0.394	—0.391
9.30	9.18	—0.385	—0.383
9.40	9.28	—0.377	—0.375

A series of corneal sections with parallel surfaces and thickness of 0.12 mm. where the following designations prevail: r_a and r_p are the anterior and posterior radii of curvature, respectively; D_a and D_p are the anterior and posterior paraxial vertex powers, respectively.

TABLE II

r_p	t	D_p	D_a
7.58	0.12	—0.564	—0.559
7.57	0.13	—0.612	—0.607
7.56	0.14	—0.661	—0.654
7.55	0.15	—0.709	—0.701
7.54	0.16	—0.756	—0.749
7.53	0.17	—0.806	—0.796
7.52	0.18	—0.855	—0.844
7.51	0.19	—0.904	—0.892
7.50	0.20	—0.953	—0.953
7.49	0.21	—1.000	—0.987
7.48	0.22	—1.052	—1.035
7.47	0.23	—1.102	—1.084
7.46	0.24	—1.152	—1.132
7.45	0.25	—1.202	—1.180
7.44	0.26	—1.252	—1.228
7.43	0.27	—1.302	—1.277
7.42	0.28	—1.353	—1.326
7.41	0.29	—1.403	—1.374
7.40	0.30	—1.454	—1.423
7.39	0.31	—1.505	—1.472
7.38	0.32	—1.556	—1.521
7.37	0.33	—1.608	—1.570
7.36	0.34	—1.659	—1.619
7.35	0.35	—1.711	—1.668
7.34	0.36	—1.763	—1.718
7.33	0.37	—1.815	—1.767
7.32	0.38	—1.868	—1.817
7.31	0.39	—1.920	—1.866
7.30	0.40	—1.973	—1.916
7.29	0.41	—2.025	—1.966
7.28	0.42	—2.078	—2.016
7.27	0.43	—2.132	—2.066
7.26	0.44	—2.185	—2.116

A series of corneal sections - anterior radius of curvature: 7.70 mm. with parallel surfaces where the following designations prevail: r_p is the posterior radius of curvature, t is the thickness and D_a and D_p are the anterior and posterior paraxial vertex powers, respectively.

TABLE III

axis	*cylinder**	*sign***	*sphere****	*sign*****	*new axis*
5	0.509	same	0.50	opp.	10
10	0.535	same	0.50	opp.	20
15	0.580	same	0.50	opp.	30
20	0.655	same	0.50	opp.	40
25	0.780	same	0.50	opp.	50
30	1.000	same	0.50	opp.	60
35	1.464	same	0.50	opp.	70
40	2.900	same	0.50	opp.	80
45	infinite				
50	2.900	opp.	0.50	same	100
55	1.464	opp.	0.50	same	110
60	1.000	opp.	0.50	same	120
65	0.780	opp.	0.50	same	130
70	0.655	opp.	0.50	same	140
75	0.580	opp.	0.50	same	150
80	0.535	opp.	0.50	same	160
85	0.509	opp.	0.50	same	170

Correction of 1.00 diopter of zero-equivalent, oblique astigmia where the following designations prevail: cylinder* is the power of the cylindrical section; sign** is the sign of the cylindrical section (+ or —); sphere*** is the value of the residual sphere; sign**** is the sign of the residual sphere; new axis is the axis of re-orientation.

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